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## SPECIFICATION

### PROCESS FOR PRODUCING COENZYME Q<sub>10</sub>

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#### TECHNICAL FIELD

The present invention relates to a process for producing a coenzyme Q<sub>10</sub> for pharmaceutical and other uses. More particularly, the invention relates to a process for producing coenzyme Q<sub>10</sub> which comprises isolating a gene coding for the  
10 coenzyme Q<sub>10</sub> side-chain synthase, which is a key enzyme involved in the biosynthesis of coenzyme Q<sub>10</sub>, i.e. decaprenyl diphosphate synthase, from a fungal strain of the genus Saitoella and  
introducing it into a host microorganism to let it elaborate coenzyme Q<sub>10</sub>.

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#### BACKGROUND ART

The conventional technology for commercial production of coenzyme Q<sub>10</sub> comprises isolating the coenzyme from a tobacco or other plant and modifying the length of its side chain by  
20 a synthetic technique.

While it is known that coenzyme Q<sub>10</sub> is produced by a broad spectrum of organisms ranging from microorganisms, such as bacteria and yeasts, to higher animals and plants, the method comprising culturing a microorganism and extracting coenzyme  
25 Q<sub>10</sub> from the microorganism is regarded as one of the most effective production methods and has actually been exploited commercially. However, the prior art methods are invariably poor in productivity, providing for only low outputs and/or involving time-consuming procedures.

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The pathways for biosynthesis of coenzyme Q<sub>10</sub> in organisms are partly different between the prokaryote and the eukaryote but invariably comprise a complicated cascade of reactions involving many kinds of enzymes. However, these pathways are basically comprised of three fundamental steps, namely the step  
35 of synthesizing decaprenyl diphosphate as the precursor of the

prenyl side-chain of coenzyme  $Q_{10}$ , the step of synthesizing p-hydroxybenzoic acid as the basis of the quinone ring of coenzyme  $Q_{10}$ , and the step of coupling these two compounds together and effecting a serial substituent transformation to complete coenzyme  $Q_{10}$ . Of these reactions, the reaction determinant of the length of the side-chain of coenzyme  $Q_{10}$  and acknowledged to be the rate-determining step of its biosynthesis, i.e. the reaction catalyzed by decaprenyl diphosphate synthase, is considered to be the most important reaction. Therefore, in order that coenzyme  $Q_{10}$  may be produced with good efficiency, it seems worthwhile to isolate the key gene involved in said biosynthesis, namely the gene coding for decaprenyl diphosphate synthase, and utilize it for enhanced production of the enzyme. As sources of the gene, fungi capable of producing coenzyme  $Q_{10}$  in comparatively large amounts can be regarded as useful candidates.

Heretofore, genes coding for decaprenyl diphosphate synthase have been isolated from several kinds of microorganisms, such as Schizosaccharomyces pombe (JP09-173076A) and Gluconobacter suboxydans (JP10-57072A), etc., but the inherent coenzyme  $Q_{10}$  productivity of these microorganisms cannot be considered high enough and neither an efficient cultural protocol for these microorganisms nor an efficient isolation and purification procedure has been established as yet. Therefore, there has been a standing demand for isolation of a coenzyme  $Q_{10}$ -encoding gene from a microorganism capable of highly producing a coenzyme  $Q_{10}$ .

Devoted to providing a solution to the above-mentioned production problems, the present invention has for its object to isolate a gene coding for the enzyme synthesizing the coenzyme  $Q_{10}$  side chain from a fungal strain of the genus Saitoella and exploit it to advantage for the efficient microbial production of coenzyme  $Q_{10}$ .

To accomplish the above object, in the present invention, the key gene involved in the biosynthesis of coenzyme Q<sub>10</sub>, namely the gene coding for decaprenyl diphosphate synthase, was isolated from a fungal strain of the genus Saitoella in the first place. Then, this gene was introduced and allowed to be expressed in a host microorganism, such as Escherichia coli, to thereby enable the host to produce coenzyme Q<sub>10</sub> with efficiency.

The inventors of the present invention made intensive investigations for isolating such genes coding for decaprenyl diphosphate synthase from fungal strains of the genus Saitoella capable of producing comparatively large amounts of coenzyme Q<sub>10</sub> and have succeeded in isolating said genes.

The present invention, therefore, is concerned with a DNA of the following (a), (b) or (c).

(a) a DNA having the nucleotide sequence shown under SEQ ID NO:1

(b) a DNA having a nucleotide sequence derived from the nucleotide sequence of SEQ ID NO:1 by the deletion, addition, insertion and/or substitution of one or a plurality of nucleotides

and coding for a protein having decaprenyl diphosphate synthase activity

(c) a DNA which hybridizes with the DNA having the nucleotide sequence of SEQ ID NO:1 under a stringent condition

and codes for a protein having decaprenyl diphosphate synthase activity.

The present invention is further concerned with a protein of the following (d) or (e).

(d) a protein having the amino acid sequence shown under SEQ ID NO:2

(e) a protein having an amino acid sequence derived from the amino acid sequence of SEQ ID NO:2 by the deletion, addition, insertion and/or substitution of one or a plurality of amino acids

and having decaprenyl diphosphate synthase activity.

The invention is further concerned with a DNA coding for this protein.

5 The present invention is further concerned with an expression vector containing said DNA. For the expression vector of the invention, various vector systems heretofore known can be utilized and, therefore, may for example be pNTS1 as constructed by cloning the DNA having the sequence of SEQ ID NO:1 into the vector pUCNT for expression.

10 The present invention is further concerned with a transformant as constructed by transforming a host microorganism with said DNA. As the host microorganism for the invention, Escherichia coli can be used with advantage.

15 The invention is further concerned with a process for producing coenzyme Q<sub>10</sub>

which comprises culturing said transformant in a culture broth and harvesting the coenzyme Q<sub>10</sub> produced and accumulated in the resulting culture. The host microorganism for this process is not particularly restricted but may be Escherichia coli to mention a preferred example. The coenzyme Q produced by Escherichia coli is coenzyme Q<sub>8</sub> but the invention enables this microorganism to produce coenzyme Q<sub>10</sub>.

20 The inventors made intensive investigations on the isolation of the enzyme gene from a fungal strain which belongs to the genus Saitoella and is capable of producing comparatively large amounts of coenzyme Q<sub>10</sub> and succeeded in acquiring a fragment of the particular gene by a PCR technique.

25 The inventors compared the sequence of the known gene coding for decaprenyl diphosphate synthase with the genes coding for polyprenyl diphosphate synthases, namely long-chain prenyl synthases which are analogous to said known enzyme gene but differ from the same in chain length and, for the region of high homology, synthesized various PCR primers. Using these primers in various combinations, they studied PCR conditions.

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35 As a result, they found by analysis of the gene sequence that

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when a PCR using DPS-1 (5'-AAGGATCCTNYTNCAYGAYGAYGT-3') and DPS-1 1AS (5'-ARYTGNADRAAYTCNCC-3') [in the above sequences, R means A or G; Y means C or T, and N means G, A, T or C] as primers is carried out according to the protocol of heat-treatment at 94 °C x 3 minutes, followed by 40 cycles of 94 °C, 1 minute → 48 °C, 2 minutes → 72 °C, 2 minutes, a ca 220 bp fragment of the enzyme gene can be amplified from the chromosome gene of Saitoella complicata IFO 10748, a fungus belonging to the genus Saitoella.

10 Then, to acquire the full length of this enzyme gene, the chromosome gene of Saitoella complicata IFO 10748 is digested with the restriction enzyme EcoRI and inserted into a  $\lambda$  phage vector to construct a recombinant phage library. After the plaque is transferred to a nylon membrane, the plaque  
15 hybridization is carried out using the labeled PCR fragment, whereby a clone having the full-length decaprenyl diphosphate synthase gene can be obtained.

Sequencing of the decaprenyl diphosphate synthase gene occurring in the above clone reveals that the gene has the  
20 nucleotide sequence shown under SEQ ID NO:1 of SEQUENCE LISTING. The amino acid sequence deduced from the above nucleotide sequence is shown under SEQ ID NO:2. Here, a sequence characteristic of a gene coding for decaprenyl diphosphate synthase is observed.

25 The DNA of the invention may be any of the DNA having the nucleotide sequence shown under SEQ ID NO:1, the DNA having a nucleotide sequence derived from the sequence of SEQ ID NO:1 by the deletion, addition, insertion and/or substitution of one or a plurality of nucleotides and coding for a protein having  
30 decaprenyl diphosphate synthase activity, and the DNA which hybridizes with the DNA having the nucleotide sequence of SEQ ID NO:1 under a stringent condition and codes for a protein having decaprenyl diphosphate synthase activity.

The "nucleotide sequence derived by the deletion,  
35 addition, insertion and/or substitution of one or a plurality

of nucleotides" means any nucleotide sequence derived by the deletion, addition, insertion and/or substitution of a number of nucleotides of the order which can be deleted, added, inserted and/or substituted by the methods well known in the art, for example as described in, inter alia, Protein, Nucleic Acid, Enzyme, Supplemental Issue: Gene Amplification PCR Technology TAKKAJ 35 (17), 2951-3178 (1990) and Henry A. Erlich (ed.), PCR Technology (the translation edited by Ikunoshin Kato) (1990).

As used in this specification, the term "protein having decaprenyl diphosphate synthase activity" means a protein capable of synthesizing decaprenyl diphosphate in a yield of not less than 10%, preferably not less than 40%, more preferably not less than 60%, still more preferably not less than 80%, relative to the protein having the amino acid sequence shown under SEQ ID NO:2. Such yield measurements can be made by the technique which comprises reacting FDP (farnesyl diphosphate) and  $^{14}\text{C}$ -IPP (radiolabeled isopentenyl diphosphate) with the enzyme of interest, hydrolyzing the resulting  $^{14}\text{C}$ -DPP (decaprenyl diphosphate) with phosphatase, fractionating the hydrolysate by TLC, and assaying the amounts taken up in spots corresponding to the respective chain lengths (Okada et al., Eur. J. Biochem., 255, 55 to 59).

The "DNA which hybridizes with the DNA having the nucleotide sequence of SEQ ID NO:1 under a stringent condition" means a DNA obtained by colony hybridization, plaque hybridization, Southern hybridization or the like hybridization technique using the DNA having the nucleotide sequence of SEQ ID NO:1 as the probe. Anyone skilled in the art may easily acquire the objective DNA by carrying out said hybridization according to the methods described in Molecular Cloning, 2nd Edition (Cold Spring Harbor Laboratory Press, 1989).

The protein of the present invention may have the amino acid sequence shown under SEQ ID NO:2 or an amino acid sequence

derived from the amino acid sequence shown under SEQ ID NO:2 by the deletion, addition, insertion and/or substitution of one or a plurality of amino acids and having decaprenyl diphosphate synthase activity.

5        "The amino acid sequence derived by the deletion, addition, insertion and/or substitution of one or a plurality of amino acids" can be obtained by effecting such deletion, addition, insertion and/or substitution by the technology well known in the art, such as a region-specific mutagenesis  
10 technique. Specific procedures are described in Nucleic Acid Res. 10, 6487 (1982), Methods in Enzymology, 100, 448 (1983) and other literature.

The protein of the present invention preferably has an amino acid sequence showing a homology of not less than 60%,  
15 preferably not less than 70%, more preferably not less than 80%, still more preferably not less than ~~90%~~, further still more preferably not less than ~~95%~~, to the amino acid sequence shown under SEQ ID NO:2.

The "homology" is calculated by aligning two nucleotide  
20 sequences to be compared in the optimum format, counting the matched base positions (A, T, C, G, U or I) between the two sequences, dividing the count by the total number of bases compared, and multiplying the product by 100. Specifically, this calculation can be made using an analytical software such  
25 as Hitachi Soft Engineering's DNASIS, Software Development's GENETYX, or Finland CSC's Clustal X, for instance.

While the gene coding for decaprenyl diphosphate synthase must be ligated downstream of a suitable promoter for expression, an expression vector can be constructed, for example by excising  
30 a DNA fragment containing the gene with a restriction enzyme or amplifying the enzyme-encoding gene selectively by PCR, followed by cloning it into a vector having a promoter. In the present invention, the expression vector into which the DNA coding for the protein having decaprenyl diphosphate synthase  
35 activity may be inserted is not particularly restricted but may

for example be one constructed by ligating a suitable promoter to a plasmid derived from E. coli. The plasmid of E. coli origin includes pBR322, pBR325, pUC19 and pUC119, while the promoter includes T7 promoter, trp promoter, tac promoter, lac promoter and  $\lambda$ PL promoter. Further, as the expression vector of this invention, pGEX-2T, pGEX-3T, pGEX-3X (all from Pharmacia), pBluescript, pUC19 (from Toyobo), pMALC2, pET-3T and pUCNT (described in WO 94/03613), etc. can also be mentioned. Among these, pUCNT can be used with advantage. To mention a specific example, the vector pNTS $\alpha$ 1 for the expression of a decaprenyl diphosphate synthase gene can be constructed by inserting the gene having the DNA sequence shown under SEQ ID NO:1 into the expression vector pUCNT.

Then, this enzyme gene expression vector is introduced into a suitable microorganism, whereby the microorganism is rendered capable of producing coenzyme  $Q_{10}$ . The host microorganism is not particularly restricted but Escherichia coli can be used with advantage. The Escherichia coli is not particularly restricted but includes such strains as XL1-Blue, BL-21, JM109, NM522, DH5 $\alpha$ , HB101 and DH5, among others. Among these, E. coli DH5 $\alpha$  can be used with particular advantage. For example, when the expression vector pNTS $\alpha$ 1 containing the decaprenyl diphosphate synthase gene is introduced into this E. coli strain, the coenzyme  $Q_{10}$ , which the intact E. coli inherently does not produce, can be produced in a large amount. This E. coli DH5 $\alpha$  (pNTS $\alpha$ 1) has been deposited with National Institute of Bioscience and Human-Technology (Higashi 1-1-3, Tsukuba-shi, Ibaraki, Japan) under the accession number of FERM BP-6844.

Furthermore, Escherichia coli KO229 (Journal of Bacteriology, 179, 3058-3060 (1997)), the octaprenyl diphosphate synthase gene-knockout E. coli strain constructed by Kawamukai et al. as the host microorganism, is incapable of producing coenzyme  $Q_8$  and can be utilized as the host for higher production of coenzyme  $Q_{10}$ .



The gene can be used not only singly but may be introduced together with another biosynthesis-related gene into a microorganism to thereby obtain still more satisfactory results.

5 Coenzyme Q<sub>10</sub> can be produced by culturing the transformant obtained according to the invention and harvesting the product coenzyme Q<sub>10</sub> in a per se known manner. When the host microorganism is a strain of Escherichia coli, either LB broth or M9 broth containing glucose and casamino acids can be used  
10 as the culture broth. In order that the promoter may be allowed to function with efficiency, the broth may be supplemented with a certain chemical such as isopropyl-thiogalactoside or indolyl-3-acrylic acid. Culture can be carried out at 37 °C for 17 to 24 hours, for instance, optionally under aeration or  
15 agitation. In the practice of the invention, the product coenzyme Q<sub>10</sub> may be used after purification or as it is in the crude form, depending on the intended use. Isolation of coenzyme Q<sub>10</sub> from the culture can be made by using known separation and purification procedures in a suitable  
20 combination. As such known separation and purification procedures, there can be mentioned techniques utilizing solubilities, such as salting-out and solvent precipitation; techniques chiefly utilizing differences in molecular weight, such as dialysis, ultrafiltration, gel filtration and  
25 (SDS-)polyacrylamide gel electrophoresis; techniques utilizing differences in charge, such as ion exchange chromatography; techniques utilizing specific affinity, such as affinity chromatography; techniques utilizing differences in hydrophobicity, such as reversed-phase high performance  
30 liquid chromatography; and techniques utilizing differences in isoelectric point, such as isoelectric focusing, among others.

The use for the coenzyme Q<sub>10</sub> obtained according to the invention is not particularly restricted but the enzyme can be applied to pharmaceuticals with advantage.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a restriction map of the pNTS1 vector containing the decaprenyl diphosphate synthase gene.

Fig. 2 is an HPLC chart of the coenzyme Q<sub>10</sub> produced by the recombinant Escherichia coli DH5 $\alpha$  as transformed with the decaprenyl diphosphate synthase gene. ,

Fig. 3 is an HPLC chart of the coenzyme Q<sub>10</sub> produced by the recombinant Escherichia coli K0229 as transformed with the decaprenyl diphosphate synthase gene.

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## BEST MODE FOR CARRYING OUT THE INVENTION

(Example 1)

20 The chromosome DNA of Saitoella complicata IFO 10748 was prepared by the method of C. S. Hoffman et al. (Gene, 57 (1987), 267-292). Based on the homology to the known long-chain prenyl diphosphate synthase genes, PCR primers, i.e. DPS-1 (5'-AAGGATCCTNYTNCAYGAYGAYGT-3') and DPS-1 1AS (5'-ARYTGNADRAAYTCNCC-3'), were designed. In the above sequences, R stands for A or G; Y for C or T; and N for G, A, T or C. Using these primers, PCR was carried out under the conditions of heat treatment at 94 °C, 3 min. followed by 40 cycles of 94 °C, 1 min. → 43 °C, 2 min. → 72 °C, 2 min., and the PCR product was analyzed by 1.2% agarose gel electrophoresis.

25 The ca 220 bp fragment thus obtained was excised from the gel and purified using a DNA extraction kit (Sephaglas™ BrandPrep Kit, Amersham Pharmacia Biotech). Then, using a PCR product direct cloning kit (pT7BlueT-Vector Kit, NOVAGEN), the DNA was cloned into the E. coli expression vector to give pT7-SaDPS. Then, using a DNA sequencer (Model 377, Perkin-Elmer) and a DNA sequencing kit (Perkin-Elmer; ABI PRISM™ BigDye™ Terminator Cycle Sequence Ready Reaction Kit with AmptiTaQ™ DNA Polymerase, FS), DNA sequencing was carried out according to the kit manufacturer's protocol. As a result, there was obtained a sequence corresponding to the nucleotides 30 717 through 924 of SEQ ID NO:1 under SEQUENCE LISTING. The

24-137  
translation sequence thus obtained contained "GDFLLGRA" which is a characteristic region of polyprenyl diphosphate synthases and, therefore, was considered to be part of the decaprenyl diphosphate synthase gene.

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(Example 2)

24-138  
Using 0.03  $\mu$ g of a pT7-SaDPS vector containing a 220 bp DNA fragment which was considered to be the decaprenyl diphosphate synthase gene of Saitoella complicata IFO 10748, 10 PCR using primers Sa-1S (which has the sequence of 5'-GAGACCAGACGAAACGCACCA-3') and Sa-2AS (which has the sequence of 5'-TGGTGC GTTTCGTCTGGTCTC-3') was carried out [94 °C, 3 min. → (94 °C, 30 sec. → 55 °C, 30 sec. → 72 °C, 1 min.) × 25 cycles → 72 °C, 5 min. → 4 °C]. The PCR product was subjected to gel 15 electrophoresis using 1.2% agarose (Takara) and a ca 145 bp fragment was excised from the gel and purified using a DNA extraction kit (Sephaglas™ BrandPrep Kit; Amersham Pharmacia Biotech). Using about 100 ng of this DNA fragment, 20 Nucleic Acid Labeling System (Amersham Pharmacia Biotech).

(Example 3)

24-139  
The chromosome DNA of Saitoella complicata IFO 10748 was digested with the restriction enzyme EcoRI and electrophoresed 25 through 0.8% agarose gel. This gel was denatured with alkali (0.5 M NaOH, 1.5 M NaCl) and neutralized (0.5 M Tris-HCl (pH 7.5), 1.5 M NaCl), after which HYBOND N + filter (Amersham) was placed on the gel and the Southern transfer was carried out using 20 × SSC overnight. This filter was dried and heated at 80 °C 30 for 2 hours and using ECL Direct Nucleic Acid Labeling/Detection System (Amersham Pharmacia Biotech), Southern hybridization and detection were carried out. Thus, using Gold Hybridization Solution (Amersham Pharmacia Biotech), prehybridization was performed at 42 °C for 1 hour.

35 The chemiluminescence-labeled probe was heated at 95 °C

for 5 minutes, quenched on ice, and added to the prehybridization solution used for filter prehybridized and the hybridization was carried out at 42 °C for 22 hours. This filter was washed with 0.5 × SSC solution containing 6 M urea and 0.4% SDS at 42 °C twice for 20 minutes each and, then, washed with 2 × SSC solution at room temperature twice for 5 minutes each. This filter was immersed in Enhanced Chemiluminescence Reagent (product of Amersham Pharmacia Biotech) and, then, exposed in intimate contact with X-ray film to detect a black exposure band.

As a result, the probe was found to have firmly hybridized with a ca. 10 kbp EcoRI restriction fragment.

(Example 4)

The chromosome DNA of Saitoella complicata IFO 10748 was digested with the restriction enzyme EcoRI and electrophoresed through 0.8% agarose and a ca. 10 kbp fragment of the DNA was excised from the gel and purified to prepare a DNA fragment for cloning. Using λ-DASHII Phage Kit (product of Stratagene), the above DNA fragment was inserted into the EcoRI site of its phage and the packaging was made using In Vitro Packaging Kit (Amersham). Escherichia coli XL1-Blue MRA (P2) was infected and layered on NZY plate medium (5 g/L NaCl, 2 g/L MgSO<sub>4</sub>·7H<sub>2</sub>O, 5 g/L yeast extract, 10 g/L NZ amine, 18 g/L agar (pH 7.5)) together with NZY soft agar (the agar only of NZY plate medium, 8 g/L) for use as a plaque. This was transferred to HYBOND N + filter (product of Amersham), denatured with alkali (0.5 M NaOH, 1.5 M NaCl), neutralized (0.5 M Tris-HCl (pH 7.5), 1.5 M NaCl), dried, and heated at 80 °C for 2 hours.

Using 9 filters heated as above, the prehybridization and the hybridization using the chemiluminescence-labeled probe were carried out as in Example 3 and the filters were rinsed. Each filter was then dried and exposed in intimate contact with X-ray film and the phage plaque corresponding to the black exposure spot was separated. The phage of the separated plaque

was used to infect E. coli in the same manner as above and transferred to the filter and the hybridization was carried out again for confirmation. As a result, 6 phage clones could be selected.

5        Using a suspension of the phage, PCR was carried out using said Sa-1S and Sa-2AS primers, and as a result, a 145-bp DNA fragment could be detected in 6 clones. Therefore, the phage DNA was prepared from the recombinant  $\lambda$ -DASHII phage particles according to Laboratory Manual for Genetic Engineering (Masami  
10 Muramatsu, Maruzen, 1990). For subcloning, the phage DNA thus prepared was digested with the restriction enzymes SalI and SacI and electrophoresed through 0.8% agarose gel. This gel was denatured with alkali (0.5 M NaOH, 1.5 M NaCl) and neutralized (0.5 M Tris-HCl (pH 7.5), 1.5 M NaCl). Then, a HYBOND N + filter  
15 (Amersham) was placed on the gel and subjected to Southern transfer using 20  $\times$  SSC overnight. This filter was dried and heated at 80  $^{\circ}$ C for 2 hours, after which the Southern hybridization and detection were carried out using ECL Direct Nucleic Acid Labeling/Detection System (Amersham Pharmacia  
20 Biotech). Thus, using Gold Hybridization Solution (Amersham Pharmacia Biotech), the prehybridization was carried out at 42  $^{\circ}$ C for 1 hour.

      The chemiluminescence-labeled probe was heated at 95  $^{\circ}$ C for 5 minutes, quenched on ice, and added to the  
25 prehybridization solution used for filter prehybridized and the hybridization was carried out at 42  $^{\circ}$ C for 22 hours. This filter was washed with 0.5  $\times$  SSC containing 6 M urea and 0.4% SDS at 42  $^{\circ}$ C twice for 20 minutes each and, then, with 2  $\times$  SSC at room temperature twice for 5 minutes each. The filter was immersed  
30 in Enhanced Chemiluminescence Reagent (Amersham Pharmacia Biotech) and exposed in intimate contact with X-ray film to detect a black exposure band.

      As a result, the probe was found to have intimately hybridized with a ca. 4.5 kb fragment as obtained by digestion  
35 with the restriction enzyme SalI and a ca. 3.5 kb fragment as

obtained by digestion with SacI.

The phage DNA was digested with the restriction enzymes SalI and SacI and electrophoresed through 0.8% agarose gel. The restriction fragment corresponding to the position and size of the black exposure band was excised from the gel and purified using a DNA extraction kit (Sephaglas™ Brand Prep Kit; Amersham Pharmacia Biotech). Then, using a DNA sequencer (Model 377, Perkin-Elmer Corp.) and a DNA sequence kit (Perkin-Elmer Corp., ABI PRISM™ BigDye™ Terminator Cycle Sequence Ready Reaction Kit with AmptiTaq™ DNA polymerase, FS), the sequencing was carried out in accordance with the manufacturer's protocol.

As a result, it was found that the SalI site and SacI site are located at positions 1124 and 1241, respectively, of SEQ ID NO:1 under SEQUENCE LISTING and that neither fragment contained the C-terminal. So, for SalI, which is the upstream one of the two restriction enzymes, in the decaprenyl diphosphate synthase gene, the remaining fragments were examined. As a result, a 3 kbp fragment was found to contain a sequence including a terminal region of the SacI fragment up to the termination codon. By analyzing these 3 restriction fragments, the full-length sequence of the decaprenyl diphosphate synthase gene could be elucidated. Of the three DNA fragments, the ca 1.6 kbp fragment was sequenced. The result is shown as SEQ ID NO:1 under SEQUENCE LISTING. Moreover, the amino acid sequence deduced from the above DNA sequence is shown as SEQ ID NO:2.

Comparison of the DNA sequence thus obtained with that of the decaprenyl diphosphate synthase gene of Saccharomyces cerevisiae as described in Journal of Biological Chemistry, 265, 13157-13164 (1990) revealed about 48% homology on the amino acid level as analyzed using Hitachi Soft Engineering's DNASIS software. Comparison with the decaprenyl diphosphate synthase derived from Schizosaccharomyces pombe as described in Japanese Kokai Publication Hei-9-173076 by means of DNASIS revealed 49% homology on the amino acid level.

(Example 5)

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In order to selectively excise the gene region coding for decaprenyl diphosphate synthase from the prepared phage DNA, PCR was carried out using synthetic DNA primers Sa-N1 (which has the sequence of 5'-AACATATGGCCTCACCAGCACTGCGG-3') and Sa-C (which has the sequence of 5'-AAGAATTCCTATCTTGACCTAGTCAACAC-3') in otherwise the same manner as in Example 3. After digestion with the restriction enzymes NdeI and EcoRI, the fragment was inserted into the expression vector pUCNT (disclosed in WO 94/03613) to construct the decaprenyl diphosphate synthase gene expression vector pNTS1. The restriction map of the expression vector pNTS1 thus obtained is shown in Fig. 1. It is to be noted that DPS represents the coding region of the decaprenyl diphosphate synthase gene.

(Example 6)

The decaprenyl diphosphate synthase gene expression vector pNTS1 constructed as above was introduced into Escherichia coli DH5 $\alpha$ . The microorganism was shake-cultured in 10 mL of LB broth at 37 °C overnight and the cells were harvested by centrifugation (3000 rpm, 20 min.).

The cells were suspended in 1 mL of 3% aqueous solution of sulfuric acid and heat-treated at 120 °C for 30 minutes. Then, 2 mL of 14% aqueous solution of sodium hydroxide was added and the mixture was further heat-treated at 120 °C for 15 minutes. The lysate obtained was extracted with 3 mL of hexane-isopropyl alcohol (10:2), and after centrifugation, 1.5 mL of the organic layer was separated and evaporated to dryness under reduced pressure. The residue was dissolved in 200  $\mu$ L of ethanol and a 20  $\mu$ L portion of the solution was subjected to HPLC analysis (LC-10A, Shimadzu Corporation). Fractionation was carried out using a reversed-phase column (YMC-pack ODS-A, 250  $\times$  4.6 mm, S-5  $\mu$ m, 120 A) and, as the mobile phase, ethanol-methanol (2:1)

and the coenzyme Q<sub>10</sub> produced was detected from the absorbance at the wavelength of 275 nm. The result is shown in Fig. 2. As can be seen from Fig. 2, it was found that when the decaprenyl diphosphate synthase gene is introduced into a host and allowed  
5 to be expressed, the resulting recombinant Escherichia coli produces coenzyme Q<sub>10</sub> which E. coli in general inherently does not produce.

The recombinant E. coli DH5 $\alpha$  (pNTS $\alpha$ 1) obtained as above has been deposited with National Institute of Bioscience and  
10 Human-Technology (Higashi 1-1-3, Tsukuba-shi, Ibaraki, Japan) as of Heisei 11, August 17 (accession number FERM BP-6844).

(Example 7)

The octaprenyl diphosphate synthase gene-knockout  
15 Escherichia coli KO229 constructed by Kawamukai et al. is known to retain the gene supported on the spectinomycin-resistant plasmid (pKA3) and die on dropout of said plasmid (Journal of Bacteriology, 179, 3058-3060 (1997)). The pNTS $\alpha$ 1 was introduced into the above knockout strain, culturing the  
20 microorganism in 10 mL of ampicillin-containing LB broth by shake culture at 37 °C overnight, subculturing 1% of the culture in 10 mL of fresh ampicillin-containing LB broth and culturing the microorganism further by shake-culture at 37 °C overnight, and after 9 cycles of the above cultural procedure, selecting  
25 the strain growing on ampicillin-containing LB plate medium but not growing on pectinomycin-containing LB plate medium.

(Example 8)

The pNTS $\alpha$ 1-transfected strain constructed in Example 7  
30 was shake-cultured in 10 mL of LB broth at 37 °C overnight and the cells were harvested by centrifugation (3000 rpm, 20 min.).

The cells were suspended in 1 mL of 3% aqueous solution of sulfuric acid and heat-treated at 120 °C for 30 min. Then, 2 mL of 14% aqueous solution of sodium hydroxide was added and  
35 the mixture was further heat-treated at 120 °C for 15 minutes.



The lysate cells were extracted with 3 mL of hexane-isopropyl alcohol (10:2) and centrifuged to recover 1.5 mL of the organic layer and the solvent was evaporated to dryness under reduced pressure. The residue was dissolved in 200  $\mu$ L of ethanol and  
5 a 20  $\mu$ L portion of the solution was subjected to HPLC analysis (LC-10A, Shimadzu Corporation). Fractionation was carried out by using a reversed-phase column (YMC-pack ODS-A, 250  $\times$  4.6 mm, S-5  $\mu$ m, 120 A) and, as the mobile phase, ethanol-methanol (2:1) and the product coenzyme Q<sub>10</sub> was detected from the absorbance  
10 at the wavelength of 275 nm. The result is shown in Fig. 3. It is clear from Fig. 3 that as the decaprenyl diphosphate synthase gene was introduced and allowed to be expressed, the  
host Escherichia coli was enabled to produce coenzyme Q<sub>10</sub> which  
it inherently does not produce and enabled to be transformed  
15 so as to yield coenzyme Q<sub>10</sub> in an increased amount more than that of the coenzyme Q<sub>8</sub> producer E. coli strain.

#### INDUSTRIAL APPLICABILITY

The gene coding for the key enzyme associated with the  
20 biosynthesis of coenzyme Q<sub>10</sub>, namely decaprenyl diphosphate synthase, was isolated from fungi of the genus Saitoella and its nucleotide sequence was elucidated. Furthermore, the gene was successfully introduced and expressed in Escherichia coli. By utilizing the technology of the invention, coenzyme Q<sub>10</sub> in  
25 use as a pharmaceutical can be produced with improved efficiency.